ACOUSTIC STUDIES IN VERTEBRATES – APPLICATIONS OF MACHINE LEARNING TECHNIQUES

Theses

ZSEBŐK SÁNDOR

EÖTVÖS LORÁND UNIVERSITY

BIOLOGICAL DOCTORAL SCHOOL

PROGRAM OF ZOOTAXONOMY, ANIMAL ECOLOGY AND HIDROBIOLOGY

LEADER OF THE SCHOOL: DR. ANNA ERDEI

LEADER OF THE PROGRAM: DR. JÁNOS TÖRÖK

SUPERVISORS:

DR. JÁNOS FARKAS, PHD

DR. KIRILL MÁRK ORCI, PHD

EÖTVÖS LORÁND UNIVERSITY

DEPARTMENT OF SYSTEMATIC ZOOLOGY AND ECOLOGY

BUDAPEST

2012

Animal bioacoustic studies are especially important in taxonomical, faunistic, ecological and evolutionary research as well as in practical nature conservation. In this thesis, I introduce the classification and clustering applications in bioacoustics, and describe five studies connected with this topic.

1. *Describing the echolocation call characteristics of Eudiscopus denticulus*

1.1 Introduction

To date, only a handful of specimens of the disc-footed bat (*Eudiscopus deticulus,* Vespertilionidae) were found in South-East Asia and despite the fact that it was described 80 years ago (Osgood 1932) the information on this species can be summarized in few lines. Its echolocation behaviour, which would be particularly important to localize the species and get more information about its distribution and ecology, remained totally unknown. In the course of a biodiversity survey in Vietnam, October 2008, echolocation calls of three individuals of *Eudiscopus denticulus* were recorded and their echolocation call characteristics are described herewith with the purpose that the species could be found easier during acoustic surveys in South-East Asia.

1.2 Material and methods

Echolocation calls of three individuals were recorded in Vietnam with ultrasound detector. Altogether 602 echolocation calls were segmented. From the pool of the common calls 96 were selected randomly (32 calls from each individual) to describe the call parameters with statistical tools. In order to make predictions for the dynamics of the call shape, correlations between the relevant parameters.

1.3 Results

- The echolocation call parameters of *Eudiscopus denticulus* were described first time.
- Based on the structure of the calls we predict this species as a so called edge-and-space aerial forager.

1.4 Conclusions

Based on the results, the acoustic identification of the species on the field is possible, and finding the species might be easier in the future studies.

2. Acoustic discrimination of *Pipistrellus kuhlii* and *Pipistrellus nathusii* and its application to assess changes in species distribution

2.1 Introduction

A rapid range expansion of *Pipistrellus kuhlii* can be observed throughout Europe based on new records gathered in the last two decades (Sachanowicz et al. 2006). Data of new occurrences were obtained by different methods (mist netting, dead specimens, checking buildings for roosts, etc.), providing only a rough picture about the exact pattern of the expansion (Fehér 1995, 2007). The aim of this study was to show an effective acoustic method that can be used for quantifying the differences in the occurrence of *P. kuhlii* in two given areas or within the same area at different times. Therefore this method can be used to investigate the process of area expansion in this species. The large overlap in the echolocation call parameters of *P. kuhlii* and *P. nathusii* made it necessary to create a sound library from the calls of the two species.

2.2 Material and methods

Echolocation calls of *P. nathusii* and *P. kuhlii* were collected from free flying specimens. Quadratic discriminant function analysis with 10-fold cross-validation was applied to discriminate the two species. In seventy-one settlements in two areas of Hungary (Northern and Southern Hungary) were visited once in the second half of June 2008, and we conducted a point-counting survey with recording echolocation calls from these two species. Using the discriminant functions we identified the sequences as *P. kuhlii* or *P. nathusii* with a self-written MATLAB script.

2.3 Results

- We developed a Hungarian sound library for the 2 species and a classification system to discriminate them.

- Based on the results of the point-counting survey we can claim that *P. kuhlii* is common in the South and rare in the North of Hungary.

2.4 Conclusions

By means of our method it's possible to conduct a well designed sampling study to follow the area expansion of *P. kuhlii* in the future in Hungary. The data, we collected from the field, can be a base of the next studies to follow the changes in time.

3. The relationship between the compositional features of song and the paring speed in collared flycatcher

3.1 Introduction

Repertoire size, which is the number of unique song elements (i.e. syllables) that an individual possesses, describes the complexity of bird song, an important target of female preference (Catchpole & Slater 2008). Repertoire size does not necessary describe biological functions, because females are unlikely to count and compare the full repertoire of males due to various constraints. Instead, they more likely compare short syllable sequences, during which the presence/absence of particular syllables may drive mating decisions. If specific syllables have coherent consequences for mate attraction, we predict that males that compose their repertoires from the same syllables realize similar mating success, and the attraction value of syllables is repeatable across males. We tested these predictions based on a population-wise syllable library of the Hungarian population of the collared flycatcher (Ficedula albicollis).

3.2 Material and methods

First, we built a sound library, and then we clustered the syllables in a semi automatic way with the support of Decision Tree classification method. We applied a tree clustering method to hierarchically classify males based on the degree of repertoire overlap. We then used a phylogenetic method to match the hierarchically structured song data with pairing speed as a measure of mating success. We partitioned the variance components of pairing speed to examine whether it varies consistently within syllables and across males. We conducted correlative investigations between the pairing speed and the geographical

distance between males, the physical characteristics of the syllables, as well as the relative abundance of syllables in the population.

3.3 Results

- These approaches revealed that males using similar syllables also find a breeding partner at a similar speed.
- We showed that the consequences of particular syllables for mating are repeatable across males.
- We derived a positive relationship between the physical distance between pairs of males and their repertoire overlap.
- We were unable to demonstrate that syllables related to higher mating success are more common in the population or they would have special physical characteristics.

3.4 Conclusions

Our results infer that individual-specific song organization may be more relevant from the listener's perspective than repertoire size, thus the specific functions of individual syllables are generally overlooked in studies of bird song. Our results imply that individual-specific song organization may be relevant for sexual selection.

4. Acoustic identification of 6 European shrew species

4.1 Introduction

Despite of the literature told fact that shrews are very vocal animals (Churchfield 1990), we know very little about their acoustic behaviour. Take into account of the species number of shrews we can claim they are one of the least studied mammals from acoustic viewpoint. Twittering sounds produced by shrews generally, hence the question was risen: can we use these calls as acoustic cues for monitor shrew species in the field? Our study offers the first comprehensive analysis of twittering calls of these 6 Central European shrew species. Its main objectives are to develop a twittering call library for the six species, to describe the characteristics of the calls and explore the degree of call plasticity and to assess whether calls may be unambiguously used for shrew species identification in field studies.

4.2 Material and methods

In this study, we present the first detailed analysis of twittering calls from 6 shrew species (*Sorex minutus, Sorex araneus, Neomys fodiens, Neomys anomalus, Crocidura russula, and Crocidura leucodon)* occur in Central Europe. Species identification accuracy is investigated in two steps. Firstly, we show how feasible the species discrimination based on the averaged acoustic parameters of individual calls by means of Support Vector Machine (SVM) method. Secondly, we make groups from the very diverse calls implemented by Self-Organizing Maps (SOM), and we conduct the SVM classification of individuals based on the relative abundances of call types.

4.3 Results

- I provided the first detailed description of the twittering calls in 6 European shrew species.
- The species discrimination based on the averaged acoustic parameters of individual calls reaches the 57% accuracy.
- Based on the classification of the relative abundances of call types I provided a species identification with 76% accuracy.

4.4 Conclusions

Using these non perfect classification models, we are able to use the calls recorded on the field for comparative studies, where we are interested in the differences of the abundance in shrew species between areas or in the same area from different time without disturbance of these animals.

5. Comparing repertoire sizes by means of Minimum Spanning Tree method

5.1 Introduction

Measuring the repertoire size of birds is one of the most important method in behaviour ecology (Catchpole & Slater 2008). In several species males with higher repertoire size reach higher mating success (Soma & Garamszegi 2011). However, quantifying the repertoire size can be cognitively challenging and largely subjective in high repertoire species. In community ecology, measuring the functional diversity without clustering the

data is related to a similar problem (Petchey & Gaston 2006). Our main aims were to describe the application possibilities of the Minimum Spanning Tree (MST) in acoustic studies, and using this technique for comparing repertoire sizes in collared flycatcher individuals.

5.2 Material and methods

In the first step I conducted simulations on generated data with different number of elements, variance, size and number of groups and studied the effect of these variables on the length of MST. In the second part of the study I compared the repertoire sizes of the collared flycatcher individuals using manual, semi-automatic clustering methods and the MST.

5.3 Results

- I provide the first description of using the functional diversity concept in bioacoustics.
- I made suggestions of the use of MST in bioacoustic studies.
- I proved the usability of MST in comparing repertoire sizes in collared flycather.

5.4 Conclusions

The MST technique can be used for quantifying acoustic diversity without subjective data clustering, hence this method is potentially applicable for acoustic repertoire studies in many taxa and organizing levels.

REFERENCES:

Catchpole, C. K. & Slater, P. J. B. 2008. Bird song: biological themes and variations. Second edition. Cambridge University Press.

Churchfield, J. 1990. The natural history of shrews. Christopher Helm, London.

Fehér, C. E. 1995. A fehérszélű denevér (Pipistrellus kuhli) első magyarországi adatai. [First data of Kuhl's pipistrelle (Pipistrellus kuhli) from Hungary.] Denevérkutatás - Hungarian Bat Research News 1: 16-17.

Fehér, C. E. 2007. Fehérszélű törpedenevér - Pipistrellus kuhlii (Kuhl, 1819) - Pp. 79-80. In: Bihari, Z., Csorba, G. & Heltai, M. (eds): Magyarország emlőseinek atlasza. [Atlas of mammals of Hungary.] Kossuth Kiadó, Budapest.

Petchey, O. L. & Gaston, K. J. 2006. Functional diversity: back to basics and looking forward. Ecology Letters 9:741-758.

Sachanowicz, K., Wower, A., & Bashta, A.-T. 2006. Further range extension of Pipistrellus kuhlii (Kuhl, 1817) in central and eastern Europe. Acta Chiropterologica 8:543-548.

Soma, M. & Garamszegi, L. Z. 2011. Rethinking birdsong evolution: Meta-analysis of the relationship between song complexity and reproductive success. Behavioral Ecology 22:363-371.

SCIENTIFIC PUBLICATIONS

Papers with impact factor:

Estók, P., **Zsebők, S.**, & Siemers, B. M. 2010. Great tits search for, capture, kill and eat hibernating bats. Biology Letters 6:59-62.

Garamszegi, L. Z., **Zsebők, S.**, & Török, J. 2012. The relationship between syllable repertoire similarity and pairing success in a passerine bird species with complex song. Journal of Theoretical Biology 295:68-76.

Pintér, O., Péczely, P., **Zsebők, S.**, & Zelena, D. 2011. Seasonal changes in courtship behavior, plasma androgen levels and in hypothalamic aromatase immunoreactivity in male free-living European starlings (Sturnus vulgaris). General and Comparative Endocrinology 172:151-157.

Zsebők, S., Estók, P., & Görföl, T. 2012. Acoustic discrimination of Pipistrellus kuhlii (Kuhl, 1817) and Pipistrellus nathusii (Keyserling & Blasius, 1839) (Chiroptera: Vespertilionidae) and its application to assess changes in species distribution. Acta Zoologica Academiae Scientiarum Hungaricae (in press).

Other papers:

Géczi I., **Zsebők S.** 2007. A Bodrogköz denevérfaunája. In: Molnár V. (ed.): Az V. Magyar Denevérvédelmi Konferencia (Pécs, 2005.december 3-4.) és a VI. Magyar Denevérvédelmi Konferencia (Mártély, 2007. október 12-14.) kiadványa. CSEMETE Egyesület, Szeged, pp. 66-72.

Görföl T. & **Zsebők S.** 2008. Kis patkósdenevér (Rhinolophus hipposideros Bechstein, 1800): új faj Tolna megye denevérfaunájában. Denevérkutatás-Hungarian Bat Research News 4.

Görföl T., Dombi I. & **Zsebők S.** 2007. Az alpesi denevér (Hypsugo savii Bonaparte, 1837) Magyarországon - a faj hazai adatainak áttekintése, új eredmények. In: Molnár V. (ed.): VI. Magyar Denevérvédelmi Konferencia (Mártély, 2007. október 12-14.) kiadványa. CSEMETE Egyesület, Szeged, pp. 85-97.

Lanszki, J., **Zsebők, S.** 2009. A Gyűrűfű Természetvédelmi Terület emlősei a Magyar Biodiverzitás Napi felmérések alapján. Natura Somogyiensis, 13: 203-209.

Zsebők, S. 2005. Impulzusszámlálás, zajszintkezelés, digitális hangfeldolgozás. - In: Molnár, V., Orbán, É. & Molnár, Z. (eds.): A II. Magyar Denevérvédelmi Konferencia (Szabadkígyós, 1999. december 4.), a III. Magyar Denevérvédelmi Konferencia (Tokaj, 2001. december 1.) és a IV. Magyar Denevérvédelmi Konferencia (Szögliget, 2003. november 22-23.) kiadványa Magyar Denevérkutatók Baráti Köre, Budapest, pp. 140-146.

Book chapters:

Bihari, Z., **Zsebők, S.** 2007. Közönséges törpedenevér – *Pipistrellus pipistrellus* Scherber, 1774. In: Bihari, Z., Csorba, G. & Heltai, M. (eds.): Magyarország emlőseinek atlasza. Kossuth Kiadó, Budapest, pp. 87-88.

Csorba, G., Németh, A., Czabán, D., Hidas, A., Molnár, V., Révay, T., Sós, E., **Zsebők, S.** és Farkas, J. 2007: A nyugati földikutya (Spalax leucodon) védelmének lehetőségei. In: Forró, L. (szerk.) A Kárpát-medence állatvilágának kialakulása, Magyar Természettudományi Múzeum, Budapest, pp: 319-325.

Zsebők, S., Bihari, Z., 2007. Szoprán törpedenevér – *Pipistrellus pygmaeus* Leach, 1825. In: Bihari, Z., Csorba, G. & Heltai, M. (eds.): Magyarország emlőseinek atlasza. Kossuth Kiadó, Budapest, pp. 89-90.

Conference abstracts:

Garamszegi, L. Zs**., Zsebők, S.,** Török, J. 2009. The organization of song when considering the population's entire repertoire. The XXII International Bioacoustic Council Conference, Lisbon, September 14th– 18th 2009. Abstracts. p. 34.

Görföl T., **Zsebők S.,** Estók P., Dombi I. 2008. The distribution patterns of Pipistrellus kuhlii (Kuhl, 1817) and Hypsugo savii (Bonaparte, 1837) in Hungary. Abstracts of the XIth European Bat Research Symposium 2008.

Puechmaille, S., Schuchmann, M., **Zsebők, S.**, Borissov, I., Teeling E. and Siemers, B. M. 2011. Female rhinolophus mehelyi prefer males with high frequency echolocation calls. XII. European Bat Research Symposium. 22nd-26th August, 2011. Vilnius, Lithuania.

Wizl V., Csorba G., Kiss I., **Zsebők S.** és Molnár Zoltán 2009. Denevérek előfordulása Budapest területén. VI. Kárpát-medencei Biológiai Szimpózium, Magyar Biológiai Társaság. Előadáskötet. 195-201.

Zsebők, S., Fehér, Cs. E., 2004. Balaton és Kis-Balaton ultrahang-detektoros denevér-faunisztikai vizsgálata egy új automatikus hangfeldolgozó program (ACMS) segítségével. In: Batáry, P., Báldi, A., Dévay Gy. (szerk). 2. Szünzoológiai Szimpózium, Előadások és poszterek összefoglalói.

Zsebők, S., Németh, A., Czabán D., Rózsás, A., Farkas, J. & Csorba, G. 2007. Gathering behavioural information on the endangered hungarian mole rat (Spalax leucodon) by means of an acoustic method. HYSTRIX The Italian Journal of Mammalogy, (V. European Congress of Mammalogy Siena, Italy 21th – 26th Sep 2007). (N.S.) – VOL. I, SUPP. 2007. p 185.

Zsebők, S., Török, J., Garamszegi, L. Zs. 2009. Fully and semi-automated analyses of bird song based on machine learning approaches. The XXII International Bioacoustic Council Conference, Lisbon, September 14th– 18th 2009. Abstracts. p. 81.

Zsebők, S., Czabán, D., Farkas, J. 2009. Automatic acoustic identification of shrew species in the field – new potencial monitoring technics. The XXII International Bioacoustic Council Conference, Lisbon, September 14th– 18th 2009. p. 82.

Zsebők, S., Greif, S., Schmieder D. and Siemers B. M. 2011. The effect of mirror orientation on bats' perception of echoacoustic mirror images. XII. European Bat Research Symposium . 22nd-26th August, 2011. Vilnius, Lithuania.

Zsebők, S. & Garamszegi, L. Zs. 2011. Classify or not? Quantifying repertoire size when it seems impossible. The XXIII meeting of the International Bioacoustics Council, La Rochelle, 12nd-16th 2011. Abstracts. p 88.